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Thermodynamic structure of the stratocumulus-capped boundary layer on 7 July, 1987

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1. Introduction.

As part of project FIRE a mission was carried out on 7 July 1987 to study the thermodynamic structure of a boundary layer which is in transition from a clear to a cloudy state. The NCAR-Electra flew a pattern in tight coordination with the NASA-ER2 aircraft near 122 West, 31.6 North off the coast of California. The preprocessing of this data is discussed elsewhere in this conference (Austin and Boers), so we will confine ourselves to a description of the thermodynamic structure. Our purpose is to derive the entrainment rate and the fluxes of the thermodynamic variables. To this end we will represent the data in conserved variable diagrams.

2. Mean structure.

Examination of Landsat and Multispectral Cloud Radiometer data revealed that the area was at the edge of a large cloud deck with the boundary stretching out from northeast to southwest near the 122 longitude line. Based on lidar cloud top measurements and observers notes it was determined that the cloud boundary drifted towards the east. It was therefore decided to divide the main east-west flight legs into three regions drifting with the speed of this boundary in order to derive meaningful statistics for this transition. The region towards the west was covered by small cumulus clouds, the middle was covered by broken stratocumulus, while the region towards the east was entirely cloudy. We will call these regions SM, BR, and SC (for SMall cumulus, BRoken stratocumulus, and StratoCumulus). Mean boundary layer wind speeds were out of the northwest at 14 m/s and shifting towards the west in region SC. Above the boundary layer winds shifted towards the north in region SM, while in region SC it remained constant with height. Figure 1 shows the average potential temperature and dewpoint profile for each of the three regions. From west to east the boundary layer dries, cools and rises. The atmosphere aloft in region SM contains almost the same amount of moisture as the the boundary layer, but is separated from it by a very dry layer. This dry layer has a relatively high ozone content and may originate from upper tropospheric levels. In region SC the moist layer above the boundary layer is entirely absent.

3. Conserved variable structure.

In this section we examine the thermodynamic structure in terms of total water content and saturation potential temperature. These thermodynamic variables are conserved under adiabatic translation. Mixing of air parcels and/or layers occurs along straight lines on diagrams which have these variables as their axes. Processing of the raw temperature and dewpoint measurements was similar to that of Boers and Betts (1988). We show the pressure-averaged (5 hPa interval bins) mixing diagrams in Figure 2. It appears from these diagrams that the air above the boundary layer has a different origin in the SM region than in the SC region. This is further supported by the strong shear in mean horizontal wind at the top of the boundary layer in the SM region which is absent in the SC region.

We computed the parameter dp*/dp, where p is pressure and p* the saturation pressure. This parameter reflects the degree of mixing of the boundary layer. If dp*/dp = 0.0 then the layer is well-mixed. For dp*/dp > 0.0 the layer is considered partly mixed with gradients in the extensively conserved variables. For this case study we found dp*/dp = 0.3 for the stratocumulus regime. For the subcloud layer in the broken and small cumulus regime dp*/dp decreased to 0.24. In the cloud layer in the SM and BR region dp*/dp = 1.9, 1.5 respectively.

4. Discussion and outline of further work.

Analysis of the data so far indicates that the thermodynamic structure of the lower troposhere changes dramatically from west to east (from shallow cumulus to broken stratocumulus to stratocumulus). In addition to variability in temperature, moisture and mixing line structure in the lowest 250 hPa of the atmosphere there appears to be a gradient in sea surface temperature with the colder temperatures towards the east. This colder water has the effect of retarding the breakup of the clouds from the west.

We intend to perform an analysis of the thermodynamic budget for the three different sections, so that entrainment and vertical flux structure can be computed for this case study.

Reference: R.Boers and A.K.Betts, 1988: Saturation point structure of marine stratocumulus clouds. J.Atmos.Sci., 45, 1156-1175.

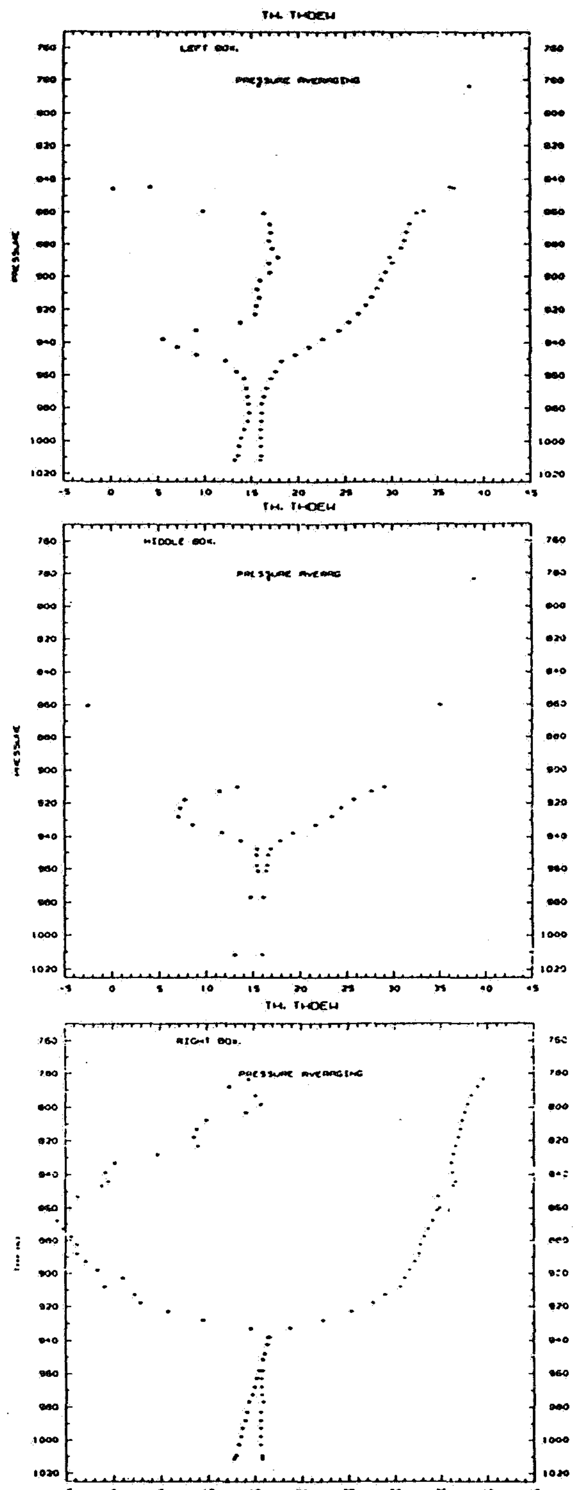

Figure 1. Potential temperature and dewpoint profiles, averaged for the three sections. The top diagram represents region SM, the middle BR and the bottom SC.

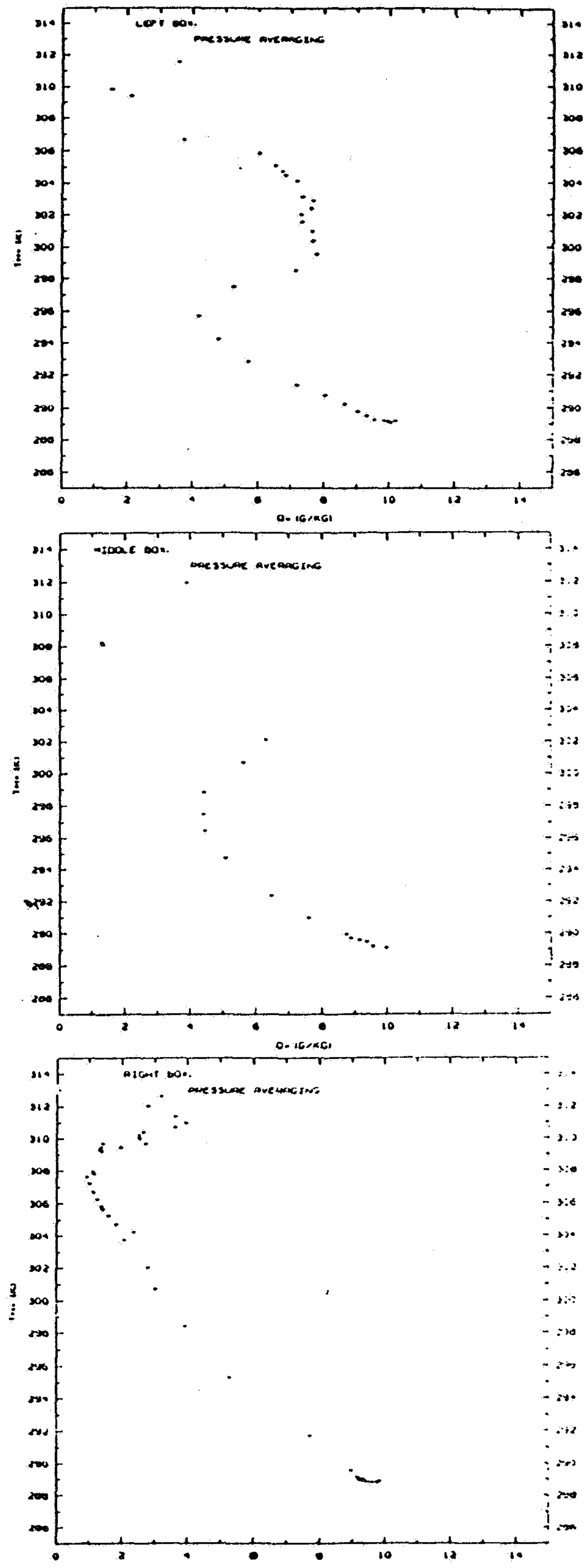

Figure 2. Saturation level potential temperature versus total water content, pressure averaged, for the three sections. The top diagram represents region SM, the middle BR, and the bottom SC.